EUROPEAN PATENT APPLICATION

(54) Appatus for monitoring respiratory muscle activity.

(57) A respiratory muscle activity monitoring apparatus is provided with a pressure sensor (10) for detecting a pressure in an air passage (3) connecting a lung ventilator (1) and the airway system of a patient and a flow rate sensor (11) for detecting a flow rate in the air passage (3). An arithmetic constant detecting unit (15) detects a resistance Rrs and an elastance Ers of the respiratory system including the airway and thorax beforehand by using detection signals from the pressure sensor (10) and the flow rate sensor (11) while the lung ventilator (1) is supplying air to the patient whose spontaneous breathing is temporarily stopped. Using an airway opening pressure Paw detected by the pressure sensor (10) and a flow rate dV/dt detected by the flow rate sensor (11), a developed pressure calculating unit (18) calculates a pressure Pmus developed by the respiratory muscles during mechanical ventilation as well as during spontaneous breathing from the expression:

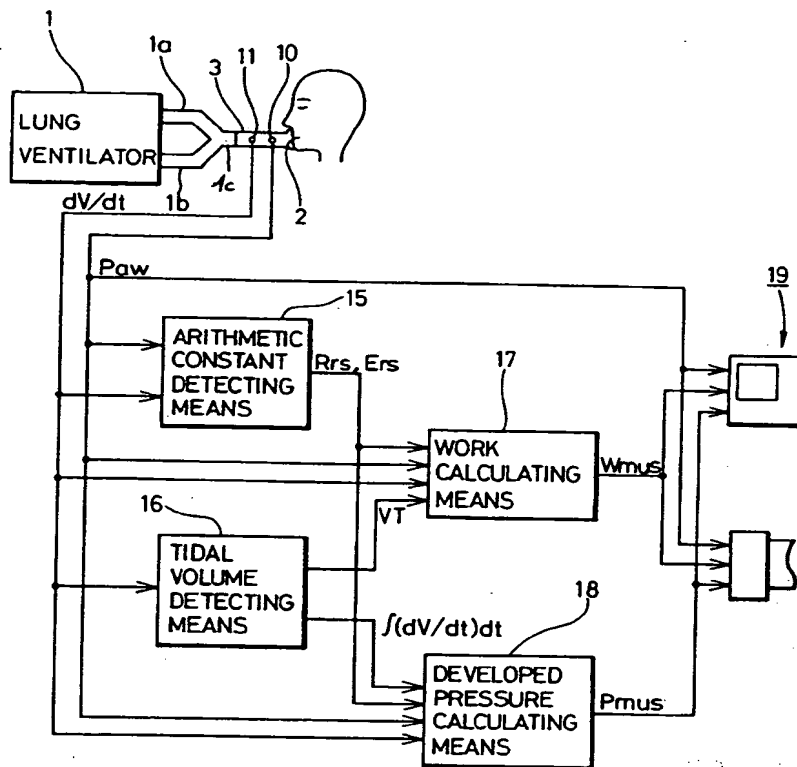$$Pmus = Paw + Rrs(dV/dt) + Ers \int(dV/dt)dt.$$

An output unit (19) displays and/or records the obtained Pmus together with waveform signal detected by the pressure sensor (10) along a common time axis. Furthermore, by detecting a tidal volume VT from flow rate, work Wmus is calculated as follows:

$$Wmus = - \int Paw(dV/dt)dt + \int Rrs(dV/dt)^2dt + (1/2)Ers(VT)^2.$$

EP 0 521 515 A1

FIG. 1

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

5   The present invention relates to a monitor apparatus for monitoring the activity of the respiratory muscles of a patient whose breathing is partially supported by a lung ventilator which interacts with patient's respiratory muscles.

DESCRIPTION OF THE RELATED ART
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In a case where a lung ventilator is used, particularly in a pressure support ventilation (PSV) mode, for a patient who manages to breathe spontaneously, the PS level and the amount of air supplied by the lung ventilator must be adjusted suitably to the condition of the patient so as to promote the spontaneous breathing and, at the same time, substantially prevent the patient's respiratory muscles from becoming
15   fatigue. In usual practice, the operational conditions of a lung ventilator are determined according to the physical conditions of the patient, such as blood gases, the respiration rate and the volume of ventilation, which are being monitored.

A paper "Mathematical Model of Pressure Support Ventilation - an Explication of Mechanical Interaction between a Lung Ventilator and Respiratory Muscles," presented by the present inventors in the 38th Annual
20   Meeting of Japan Society of Anesthesiology, March 28, 1991, suggests that the work of respiratory muscles can be obtained by assuming an equivalent circuit of the respiratory system connected with a lung ventilator, as shown in Fig. 7. In the figure E is a pressure of the supplied air, e is a spontaneous breathing source of a lung, Paw is an air pressure at the airway opening, $R1$ is an air flow resistance of the lung, and $E1$ is an elastance (an inverse of the compliance C) of the lung. A pressure inside a thoracic cavity $Pp\ell$ is
25   measured with assistance of a balloon catheter inserted in the patient's esophagus. An air-flow rate dV/dt is detected by a flow rate sensor which is installed in an air passage of the lung ventilator connected to the respiratory system. Patient's work W is calculated by integrating the value calculated by multiplication of the pressure and flow rate, as below

30    $W = \int -Pp\ell \; dV/dt \; dt$.

However, such a method of obtaining the work creates several problems. The method is invasive. Measurement precision is not satisfactory since the work performed by the respiratory muscles to drive the thorax is not considered in the method. Further, supplying air of the lung ventilation may sometimes be late
35   for the initiation of inspiration performed by the respiratory muscles, in which case the work performed by the respiratory muscles is wasted. There has not been developed a method to monitor the timing of the inspiratory activity of the respiratory muscles in order to initiate air-supplying of the lung ventilator exactly when a PS level is developed.

40 **SUMMARY OF THE INVENTION**

It is an object of the present invention to provide an apparatus for monitoring the respiratory muscle activity and, particularly, for monitoring in a noninvasive manner the timing of the respiratory muscle pressure and the airway opening pressure during air-supplying by a lung ventilator which is based on a
45   more precise equivalent circuit.

It is another object of the present invention to provide an apparatus for monitoring the respiratory muscle activity and, particularly, for measuring, in a noninvasive manner and with high precision, work performed by the respiratory muscles of a patient on a lung ventilator, including work performed by the respiratory muscles for the thorax on the premise of a precise equivalent circuit for the respiratory system
50   because it has been verified that ignoring such work for the thorax will cause a substantially large error.

According to the present invention, a pressure developed by the respiratory muscles $Pmus$ and a work performed by the respiratory muscles $Wmus$ are defined as below, based on an equivalent circuit shown in Fig. 2. This circuit includes an air-flow resistance Rw of the thorax and an elastance Ew of the thorax as well as the components of the conventional equivalent circuit shown in Fig. 7:
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$Wmus = \int Pmus(dV/dt)dt$ (1).

Using a resistance of the respiratory system $Rrs = R1 + Rw$, an elastance of the respiratory system

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$1/Crs$ = Ers = E1 + Ew and a lung volume change ΔS, a pressure at the elastance of the respiratory system is obtained as $\Delta S/Crs$ = ErsΔS. Therefore, Pmus is

$$Pmus = - Paw + Rrs(dV/dt) + Ers\Delta S$$
$$= - Paw + Rrs(dV/dt) + Ers \int (dV/dt)dt \qquad \ldots (2).$$

Thereby, Pmus, which varies as the respiratory muscles contract, is continuously detected, and Wmus is obtained as

$$Wmus = \int(- Paw + Rrs(dV/dt) + Ers\Delta S)dt \ dV/dt \qquad (3).$$

The same expression can be written

$$Wmus = - \int Paw(dV/dt)dt + Rrs \int (dV/dt)^2 dt + Ers \int \Delta Sdt \ dV/dt \qquad \ldots (4).$$

Since the amount of energy stored at the elastance is

$$Ers \int \Delta Sdt \ dV/dt = (1/2)Ers(\Delta S)^2$$

the expression (4) can be written

$$Wmus = - \int Paw(dV/dt)dt + Rrs \int (dV/dt)^2 dt + (1/2)Ers(\Delta S)^2 \qquad \ldots (5).$$

Since ΔS over an inspiratory period is a tidal volume VT,

$$Wmus = - \int Paw(dV/dt)dt + Rrs \int (dV/dt)^2 dt + (1/2)Ers(VT)^2 \qquad \ldots (6).$$

In the expressions (2) and (6), Paw, dV/dt, Rrs, Ers and VT are all parameters which can be measured or calculated utilizing a flow rate sensor and a pressure sensor that are mounted to an air passage connecting the external lung ventilator and the airway system of a patient.

Therefore, to achieve the above-mentioned objects, the present invention provides a monitor apparatus comprising: a pressure sensor for detecting an air pressure in an air passage connecting a lung ventilator and the airway system of a patient; a flow rate sensor for detecting a flow rate in the air passage; an arithmetic constant detecting means for detecting a resistance Rrs and an elastance Ers of the respiratory system including the airway and thorax beforehand by using detection signals from the pressure sensor and the flow rate sensor while the lung ventilator is supplying air to the patient whose spontaneous breathing is temporarily stopped; developed pressure calculating means for calculating a pressure Pmus developed by the respiratory muscles during a mechanical ventilation from the foregoing expression (2) using an airway opening pressure Paw detected by the pressure sensor and a flow rate dV/dt detected by the flow rate sensor; and a means for displaying and/or recording the obtained Pmus together with a waveform signal detected by the pressure sensor along a common time axis.

Since data about a waveform of the respiratory muscle pressure can be obtained in such an apparatus, the timing of operation of a lung ventilator can be adjusted with respect to the actual inspiratory initiation of the respiratory muscles, by comparing the data about the above waveform with an airway opening pressure. Thus, an unnecessary fatigue of the respiratory muscles can be substantially prevented.

A monitor apparatus according to the present invention may be provided with: a time difference calculating means detecting a time point when the thus calculated Pmus starts to decrease as an inspiration

initial point, detecting a time when the level of detection signal from the pressure sensor starts to increase as an air-supplying initial point, for obtaining a time difference between the inspiration initial point and the air-supplying initial point; and a means for displaying and/or recording data of the time difference. Thereby, the time difference between the initiation of air-supplying from a lung ventilator and the initiation of inspiratory activity of the respiratory muscles is made recognizable in digits.

Further, a monitor apparatus according to the present invention may be provided with: a pressure-time product calculating means detecting a time point when the obtained Pmus starts to decrease as an inspiration initial point, detecting a time point when the obtained Pmus starts to increase as an inspiration terminal point, for calculating a pressure-time product between the inspiration initial point and the inspiration terminal point from the expression PTP = ∫ Pmus dt; and a means for displaying and/or recording data of the pressure-time product. Thereby, an index of the amount of oxygen consumed· by the respiratory muscles, including the amount of oxygen consumed for isometric contraction that occurs during initiation of inspiration of the patient, can be obtained without requiring any measurement of the pressure in the esophagus.

Still further, a monitor apparatus according to the present invention may be provided with an expiration initiation detecting means for detecting a time point when the obtained Pmus starts to increase as an expiration initial point and for out-putting a signal indicating the initiation of expiration. Thereby, a trigger signal for stopping air-supplying in the PSV (pressure support ventilation) mode can be outputted with exact timing.

Further, a monitor apparatus according to the present invention may be provided with: a work calculating means for calculating work Wmus performed by the respiratory muscles over an inspiratory period from the foregoing expression (6); and a means for displaying and/or recording the obtained Wmus. Thereby, actual work performed by the respiratory muscles of the patient on a lung ventilator, including the work performed for the thorax, can be obtained. In a case where the lung ventilation is performed in the PSV mode for a patient who is spontaneously breathing, the respiratory muscle work of the patient can be maintained at a moderate level and fatigue of the respiratory muscles can substantially be prevented by setting the PS level and a tidal volume suitable to the patient. This monitor apparatus allows noninvasive and continuous monitoring of the respiratory muscle activity.

Further objects, features and advantages of the present invention will become apparent from the following description of the preferred embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1   illustrates the construction of a respiratory monitor apparatus, according to one embodiment of the present invention.

Fig. 2   illustrates an equivalent circuit of the respiratory system, on which the present invention is based.

Fig. 3   shows waveforms for illustrating operations of the monitor apparatus of the above embodiment, including the operation for measuring an arithmetic constant.

Fig. 4   shows waveforms for illustrating the operation of the monitor apparatus of the same embodiment.

Fig. 5   shows monitoring waveforms of the monitor apparatus of the same embodiment.

Fig. 6   illustrates the construction of a respiratory monitor apparatus, according to another embodiment of the present invention.

Fig. 7   illustrates a conventional equivalent circuit of a respiratory system.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to Fig. 1, showing the construction of an apparatus for monitoring the respiratory muscle activity according to one embodiment of the present invention, a lung ventilator 1 triggers an air driving unit when the pressure in an inspiratory air passage 1a reaches a predetermined negative pressure. The lung ventilator 1 also supports expiration through an expiratory air passage 1b. A common air passage 1c connecting both of these air passages 1a and 1b is connected to an air passage 3, whose end is connected to an endotracheal tube 2. The air passage 3 is provided with a pressure sensor 10 for detecting the pressure therein and a flow rate sensor 11 for detecting the rate of the air flow therein.

The pressure sensor 10 and the flow rate sensor 11 are connected to the following components: an arithmetic constant detecting means 15 for detecting Rrs and Crs or its inverse, i.e., Ers, by using detection signals from these sensors 10, 11 while the spontaneous breathing of a patient is temporarily stopped; a

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tidal volume detecting means 16 for obtaining a tidal volume VT by integrating dV/dt signal, which is a detection signal from the flow rate sensor 11, over an inspiratory period between the time when the lung ventilator 1 starts supplying air, i.e., when the level of dV/dt signal starts rising, and the time when the lung ventilator 1 stops supplying air, i.e, when the level of dV/dt signal crosses zero, and by correcting the
5 integrated value in accordance with the sectional area of the air passage; work calculating means 17 for calculating the work done by the respiratory muscles Wmus over an inspiratory period from the expression (6) using the Paw signal, the dV/dt signal and the VT signal; a developed pressure calculating means 18 for continuously calculating the pressure developed by the respiratory muscles Pmus from the expression (2) using the Paw signal, the dV/dt signal and the ∫(dV/dt)dt signal which is continuously supplied from the tidal
10 volume detecting means 16. Output means 19 displays and/or records data of thus-obtained work in, e.g., a graph or by numerical values, and displays and/or records both a waveform of the amplified Paw signal and a waveform of data of Pmus using a common time axis.

As shown in Fig. 3, the lung ventilator 1 supplies air at a constant level F1 of the flow rate dV/dt, and the pressure sensor 10 detects Paw while the patient's spontaneous breathing is temporarily stopped by,
15 e.g., injecting a muscle relaxant into the patient. Then, the arithmetic constant detecting means 15 detects a pressure difference P1 between a peak pressure when air-supplying from the lung ventilator is finished and an end inspiratory pressure P2, and obtains Rrs = P1/F1. Further, the arithmetic constant detecting means 15 detects the end inspiratory pressure P2 and obtains Ers = P2/(F1 x t), where t is a period of air-supplying, based on F1 x t = P2 x Crs.
20 The operation of the monitor apparatus with such a construction will be described.

When the endotracheal tube 2 connected to the lung ventilator 1 is connected to a patient, Rrs and Ers are measured as described above. The lung ventilator 1 is operated in the PSV mode. The lung ventilator 1 is triggered to supply air when the airway pressure reaches a predetermined negative level. Supplying of air of a predetermined amount and at a predetermined flow rate is repeated, with an expiratory phase
25 intervening. When the tidal volume calculating means 16 detects a sudden rise of the waveform signal (b in Fig. 4) of the detection signal dV/dt from the flow rate sensor 11 as the initiation of inspiration, the tidal volume detecting means 16 starts integration for a tidal volume VT and serially supplies ∫(dV/dt)dt signals to the developed pressure calculating means 18.

The termination of one period of air-supplying by the lung ventilator 1 is detected as a time point where
30 dV/dt turns from positive to negative (corresponding to a sudden drop of the waveform signal of the detection signal (a in Fig. 4) from the pressure sensor 10). At this point, the tidal volume calculating means 16 completes the operation for a tidal volume. Meanwhile, the work calculating means 17 calculates the work Wmus over the inspiratory period from the expression (6) using the data serially input thereto. The developed pressure calculating means 18 calculates Pmus which continuously varies from the expression
35 (2) using the data serially input thereto. The output means 19 displays the calculation waveform of Pmus (d in Fig. 5) together with the detection waveform of Paw (c in Fig. 5) practically without any delay and also the resultant Wmus of the calculation.

Due to the above noninvasive manner, it can be determined whether the timing of initiation of air-supplying by the lung ventilator is appropriate with respect to the timing of initiation of inspiration. The work
40 performed by the respiratory muscles including the work done to the thorax can accurately be measured without requiring any insertion of a balloon catheter into the esophagus. Tests have shown that a known measuring method which ignores an equivalent parameter for a thorax provides a measurement of respiratory muscle work which is at least 20 % less than the actual value of the work.

Fig. 6 illustrates a monitor apparatus employing a CPU 24 according to another embodiment of the
45 present invention. A gauge pressure converter 21 detects Paw. A differential pressure transducer 21 detects dV/dt. The Paw and dV/dt values are amplified by amplifiers 20a, 21a and then digitized by A/D converters 20b, 21b, respectively. Then, the Paw and dV/dt values are fed through an I/O port 23 to a CPU 24 as sample values. A ROM 25 stores programs for, e.g., the calculation of the constants Rrs and Ers, the calculation of a tidal volume VT, the operation of the expression (2) using these data and data about the
50 airway opening pressure Paw and the flow rate dV/dt, the calculation of a time difference based on the result of that calculation, and the operation of the expression (6), and further a program for output format. In accordance with these programs, the CPU 24 parallelly performs the necessary operations using a RAM 26 which functions as a combination of the arithmetic constant detecting means, the developed pressure calculation means, the tidal volume detecting means and the work calculation means according to the
55 present invention.

The CPU 24 also functions as a time difference calculating means. The CPU analyzes the data of Paw and Pmus in order to detect a time point when Pmus starts decreasing (corresponding to Ta of d in Fig. 5) as a time point of initiation of inspiration and to detect a time point when the level of Paw signal starts

increasing (corresponding to Tb of c in Fig. 5) as a time point of initiation of air-supplying and then to obtain a time difference ΔT between the two time points.

Further, during the same work calculation, the CPU 24 functions as an expiration initiation detecting means. The CPU 24 detects a time point when Pmus starts increasing from the minimum level (corresponding to Tc of d in Fig. 5) as a time of initiation of expiration and sends a trigger signal to the lung ventilation for stopping air-supplying. The CPU 24 is connected with a CRT 27 which displays output data processed by the CPU 24 in a predetermined output format by the control of a CRT controller 27a.

Therefore, while the lung ventilator is operated in inspiratory assist mode, the CRT 27 displays the waveforms of Paw, dV/dt and Pmus, from top to bottom in the figure, in predetermined formats and further displays the time difference ΔT and the work Wmus over the latest inspiratory period and the average work of a plurality of consecutive inspiratory periods in digits, for example, 1,5 sec, 2,0 (10^{-2} kg·m) and 1,9 (10^{-2} kg·m). Further, a trigger signal is output when expiration initiates.

To measure the pressure-time product PTP as an index of the respiratory work load which is in correlation with the amount of oxygen consumed by the respiratory muscles at initiation of inspiration during mechanical ventilation, both of the foregoing embodiments may be provided with pressure-time integrating means for detecting a time point when Pmus starts to decrease and a time point when Pmus starts to increase as inspiration initial point Ta and inspiration terminal point Tc (equivalent to an expiration initial point), respectively, and obtaining the pressure-time product PTP over the duration between the two time points by integration PTP = $\int$Pmusdt, and output means for displaying and/or recording the data of timepressure products.

The integral $\int$Pmusdt is operated by, for example, sampling a value of Pmus every 10 msec between the time points Ta and TC and obtaining pressure-time product and adding such products. Alternatively, pressure-time product with respect to respiratory rate per minute may be obtained.

When a patient connected with a lung ventilator starts inspiration, the patient must lower the pressure inside the thoracic cavity below that in the airway in order to open an inspiratory demand valve of the lung ventilator. However, during this isometric contraction until the inspiratory demand valve opens, the inspiration is not performed. In the conventional art, the pressure inside the esophagus must be measured and the measurement must be corrected with a chest-wall elastic contraction force in order to obtain a pressure-time product. On the other hand, according to the present invention, the pressure-time product including a chest-wall elastic contraction can be obtained without requiring any measurement of the esophageal pressure, as an index of the amount of oxygen consumed by the respiratory muscles including a period of isometric contraction. Thus, the variation of pressure-time product with time can be monitored.

A monitor apparatus according to the present invention cannot only be provided in a stand-alone form but also be mounted inside a lung ventilator. In addition, an inspiratory phase can be detected using the pressure sensor and the flow rate sensor provided inside the lung ventilator. The monitor apparatus of the invention can also be used to perform mechanical ventilation through a nasal trachea or an incision in the trachea. The operation of a lung ventilator can automatically be controlled in accordance with the state of the respiratory muscle activity of the patient, by feeding back work signal and time difference signal to the lung ventilator.

While the present invention has been described with respect to what are presently considered to be the preferred embodiments, it is to be understood that the invention is not limited to the disclosed embodiments. Rather, the invention is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the principles described above.

Claims

1. An apparatus for monitoring a respiratory muscle activity comprising:
   - a pressure sensor (10) for detecting an air pressure in an air passage (3) connecting a lung ventilator (1) and the airway system of a patient;
   - a flow rate sensor (11) for detecting a flow rate in the air passage (3);
   - arithmetic constant detecting means (15) for detecting a resistance Rrs and an elastance Ers of the respiratory system including the airway and thorax beforehand by using a detection signal from the pressure sensor (10) and a detection signal from the flow rate sensor (11) while the lung ventilator (1) is supplying air to the patient whose spontaneous breathing is temporarily stopped;
   - developed pressure calculating means (18) for calculating a pressure Pmus developed by the respiratory muscles during lung ventilation from the following expression

   Pmus = - Paw + Rrs(dV/dt) + Ers $\int$(dV/dt)dt

where Paw is an airway opening pressure detected by the pressure sensor (10) and dV/dt is a flow rate detected by the flow rate sensor (11); and

- output means (19) for outputting the obtained Pmus together with a waveform signal detected by the pressure sensor (10) along a common time axis.

2. An apparatus for monitoring a respiratory muscle activity comprising:
   - a pressure sensor (10) for detecting an air pressure in an air passage (3) connecting a lung ventilator (1) and the airway system of a patient;
   - a flow rate sensor (11) for detecting a flow rate in the air passage (3);
   - arithmetic constant detecting means (15, 24) for detecting a resistance Rrs and an elastance Ers of the respiratory system including the airway and thorax beforehand by using a detection signal from the pressure sensor (10) and a detection signal from the flow rate sensor (11) while the lung ventilator (1) is supplying air to the patient whose spontaneous breathing is temporarily stopped;
   - developed pressure calculating means (18, 24) for calculating a change in pressure Pmus developed by the respiratory muscles during lung ventilation using the following expression

$$Pmus = - Paw + Rrs(dV/dt) + Ers \int (dV/dt)dt$$

where Paw is an airway opening pressure detected by the pressure sensor (10) and dV/dt is a flow rate detected by the flow rate sensor (11);
   - time difference calculating means (24) detecting a time point (Ta) when the obtained Pmus starts to decrease as an inspiration initial point, detecting a time (Tb) when the level of the detection signal from the pressure sensor (10) starts to increase as an air-supplying initial point, for obtaining a time difference (ΔT) between the inspiration initial point and the air-supplying initial point; and
   - output means (19, 27) for outputting data of the time difference.

3. An apparatus for monitoring a respiratory muscle activity comprising:
   - a pressure sensor (10) for detecting an air pressure in an air passage (3) connecting a lung ventilator (1) and the airway system of a patient;
   - a flow rate sensor (11) for detecting a flow rate in the air passage (3);
   - arithmetic constant detecting means (15, 24) for detecting a resistance Rrs and an elastance Ers of the respiratory system including the airway and thorax beforehand by using a detection signal from the pressure sensor (10) and a detection signal from the flow rate sensor (11) while the lung ventilator (1) is supplying air to the patient whose spontaneous breathing is temporarily stopped;
   - developed pressure calculating means (18, 24) for calculating a change in a pressure Pmus developed by the respiratory muscles during lung ventilation using the following expression

$$Pmus = - Paw + Rrs(dV/dt) + Ers \int (dV/dt)dt$$

where Paw is an airway opening pressure detected by the pressure sensor (10) and dV/dt is a flow rate detected by the flow rate sensor (11);
   - pressure-time product calculating means (16, 17, 24) detecting a time point (Ta) when the obtained Pmus starts to decrease as an inspiration initial point, detecting a time-point (Tc) when the obtained Pmus starts to increase as an inspiration terminal point, for calculating a pressure-time product (PTP) between the inspiration initial point and the inspiration terminal point from the following expression

$$PTP = \int Pmus \, dt; \text{ and}$$

   - output means (19, 24) for outputting data of the pressure-time product.

4. An apparatus for monitoring a respiratory muscle activity comprising:
   - a pressure sensor (10) for detecting an air pressure in an air passage (3) connecting a lung ventilator (1) and the airway system of a patient;
   - a flow rate sensor (11) for detecting a flow rate in the air passage;

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- arithmetic constant detecting means (15, 24) for detecting a resistance Rrs and an elastance Ers of the respiratory system including the airway and thorax beforehand by using a detection signal from the pressure sensor (10) and a detection signal from the flow rate sensor (11) while the lung ventilator (1) is supplying air to the patient whose spontaneous breathing is temporarily stopped;
- developed pressure calculating means (18, 24) for calculating a change in the pressure Pmus developed by the respiratory muscles during lung ventilation using the following expression

$$Pmus = - Paw + Rrs(dV/dt) + Ers \int (dV/dt)dt$$

where Paw is an airway opening pressure detected by the pressure sensor (10) and dV/dt is a flow rate detected by the flow rate sensor (11); and
- expiration initiation detecting means (24) for detecting a time point (Tc) when the obtained Pmus starts to increase as an expiration initial point and outputting a signal indicating the initiation of expiration.

5. An apparatus for monitoring a respiratory muscle activity comprising:
   - a pressure sensor (10) for detecting an air pressure in an air passage connecting a lung ventilator (1) and the airway system of a patient;
   - a flow rate sensor (11) for detecting a flow rate in the air passage (3);
   - arithmetic constant detecting means (15, 24) for detecting a resistance Rrs and an elastance Ers of the respiratory system including the airway and thorax beforehand by using a detection signal from the pressure sensor (10) and a detection signal from the flow rate sensor (11) while the lung ventilator (1) is supplying air to the patient whose spontaneous breathing is temporarily stopped;
   - tidal volume detecting means (16, 24) for detecting a tidal volume (VT) by integrating the detection signal from the flow rate sensor (11);
   - work calculating means (17, 24) for calculating the work Wmus performed by the respiratory muscles over an inspiratory period from the following expression

$$Wmus = - \int Paw(dV/dt)dt + Rrs \int (dV/dt)^2 dt + (1/2)Ers(VT)^2$$

where Paw is an airway opening pressure detected by the pressure sensor (10), dV/dt is a flow rate detected by the flow rate sensor (11), and VT is a tidal volume detected by the tidal volume detecting means (16, 24); and
   - output means (19, 27) for outputting the obtained work Wmus.

6. The apparatus according to Claim 5,
   wherein the work calculating means (17, 24) calculates a mean value of works Wmus obtained in a plurality of inspiratory phases, and the output means outputs the mean value.
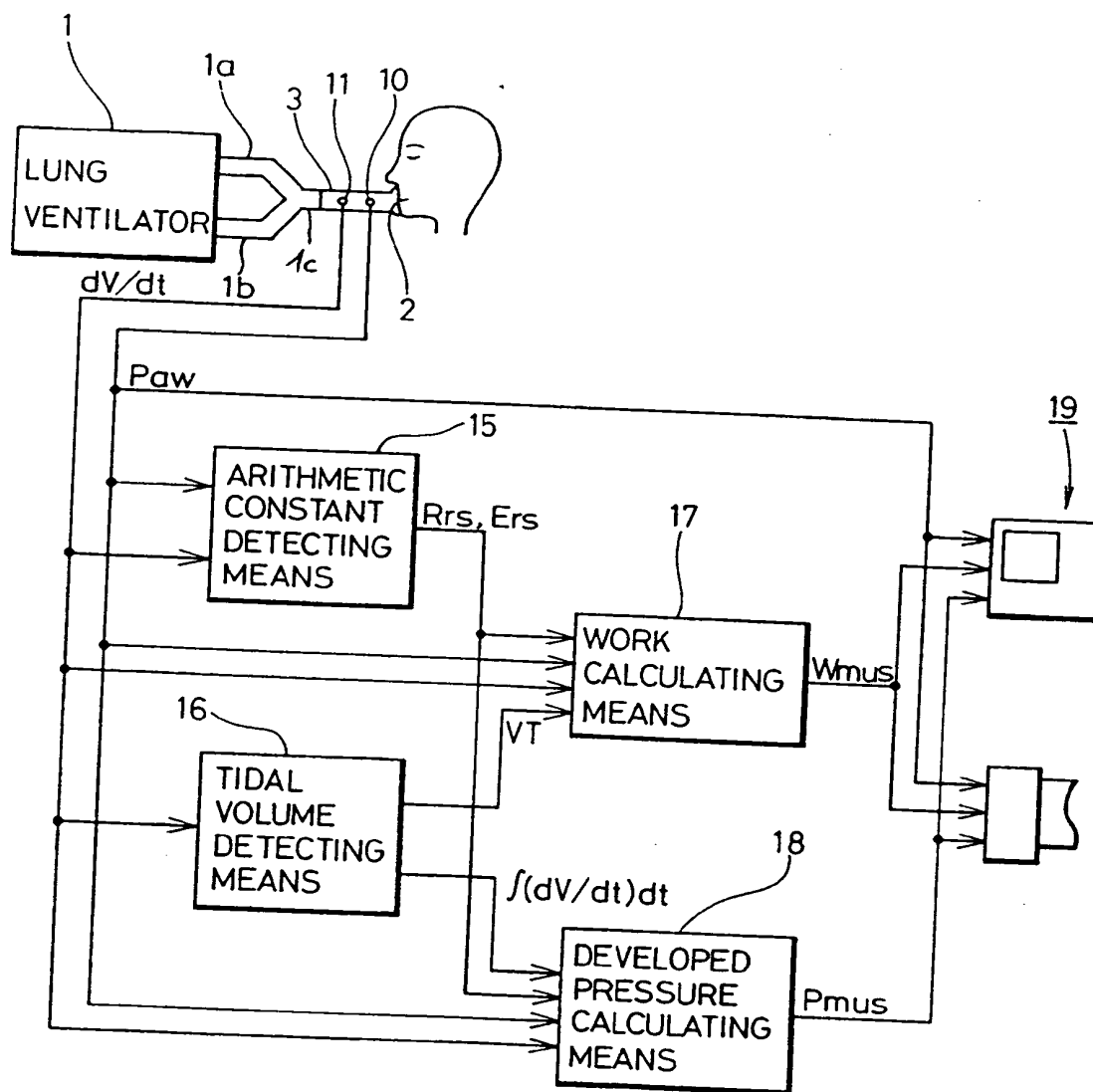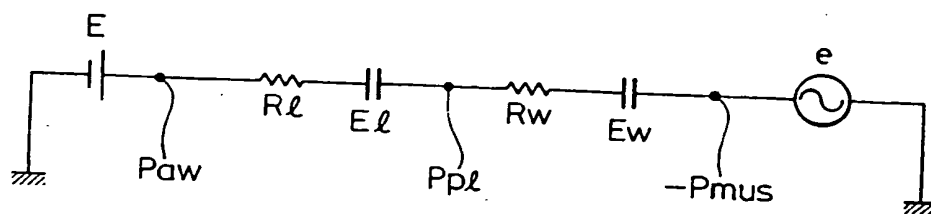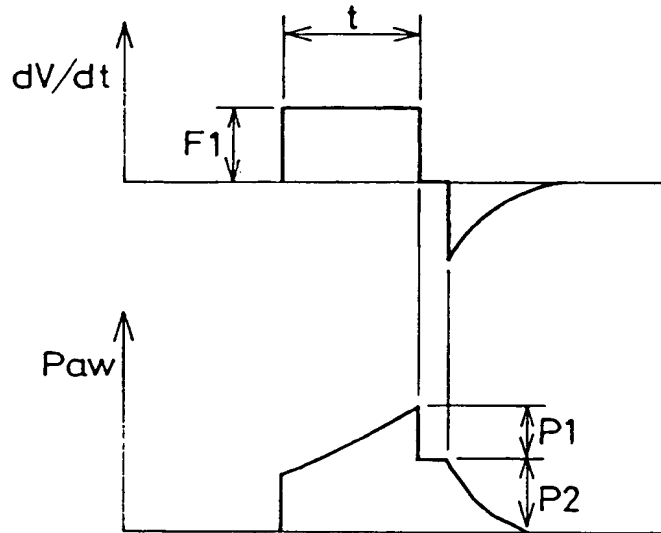
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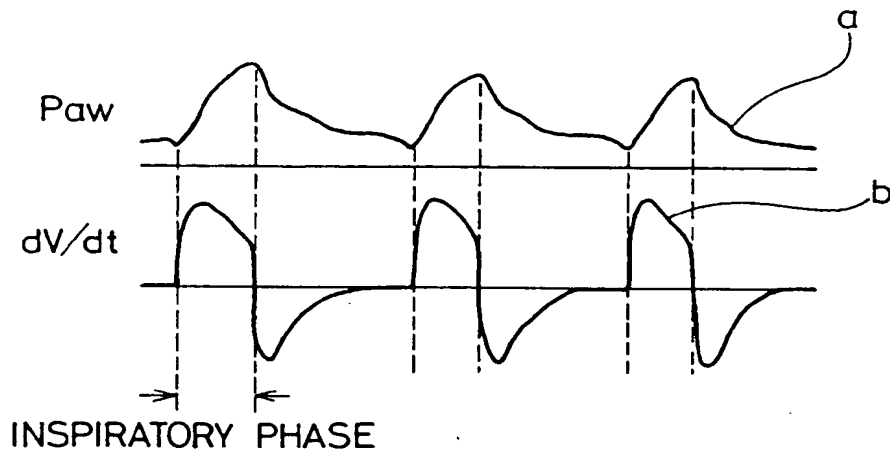
FIG. 1

FIG. 2

FIG. 3

FIG. 4
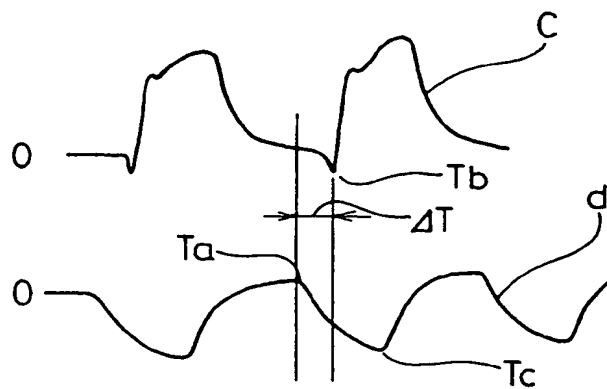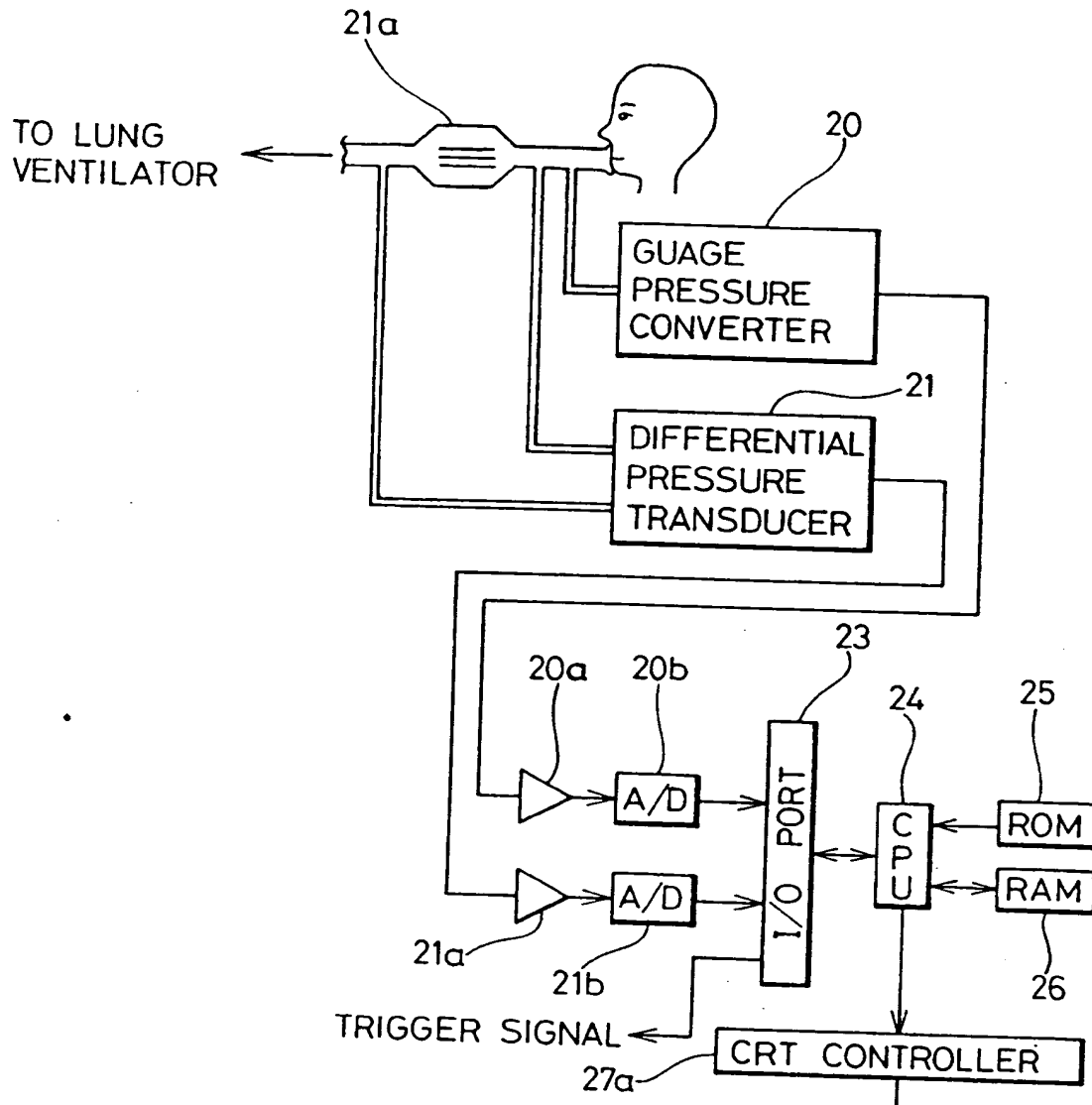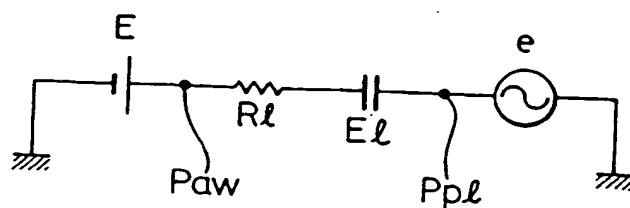
INSPIRATORY PHASE

FIG. 5

FIG. 6

TO LUNG
VENTILATOR

21a

20

GUAGE
PRESSURE
CONVERTER

21

DIFFERENTIAL
PRESSURE
TRANSDUCER

20a   20b   23   24   25

A/D

I/O PORT

CPU

ROM

A/D

RAM

21a   21b   26

TRIGGER SIGNAL

27a   CRT CONTROLLER

27

ΔT:1.5 W:2.0 mW:1.9

FIG. 7

E   e

Rl   El

Paw   Ppl

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. CL5)
X	US-A-4 005 702 (O.E.L.BARGETON ET AL)	1	A61B5/08
A	* column 1, line 14 - column 4, line 55; figure UNIQUE *	2-5	A61B5/087

A	GB-A-2 077 444 (DRÄGERWERK A.G.) * page 1, line 35 - page 3, line 46; figure UNIQUE *	1-4	

TECHNICAL FIELDS SEARCHED (Int. CL5)

A61B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
BERLIN	01 OCTOBER 1992	WEIHS J.

EPO FORM 1503 03.82 (P0401)